2011 AEC-NRC Bilateral Technical Meeting

Degradation of Boral in Spent Fuel Pools at Chinshan and Kuosheng Plants

Department of Nuclear Regulation
Atomic Energy Council, Taiwan

10th TAEC-USNRC Bilateral Technical Meeting
May 03-05, 2011

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Background Information

Plant	Reactor	Containment	Thermal（MWt）	Electric（MWe）	Commercial Date Unit 1 Unit 2
Chinshan	BWR-4 GE	Mark-I	1804	636	12/6/1978 7/16/1979
Kuosheng	BWR-6 GE	Mark-III	2943	985	12/28/1981 3/15/1983

Plant	Time of Re-rack	SFP Capacity per Unit	Loaded Unit 1 Unit 2	Rack Vendor	Boral Vendor	Neutron-Absorbing Materials
Chinshan	1986 1998	3083	2770 2744	Holtec[1]	AAR	Boral
Kuosheng	1991 2003	4398	3828 3716	Holtec ENSA[2]	AAR AAR Brooks & Perkins, Michigan[2]	Boral

1.CS SFPs contain Holtec racks only.
2.KS SFPs contain Holtec racks and ENSA racks.

Experience of Chinshan NPP

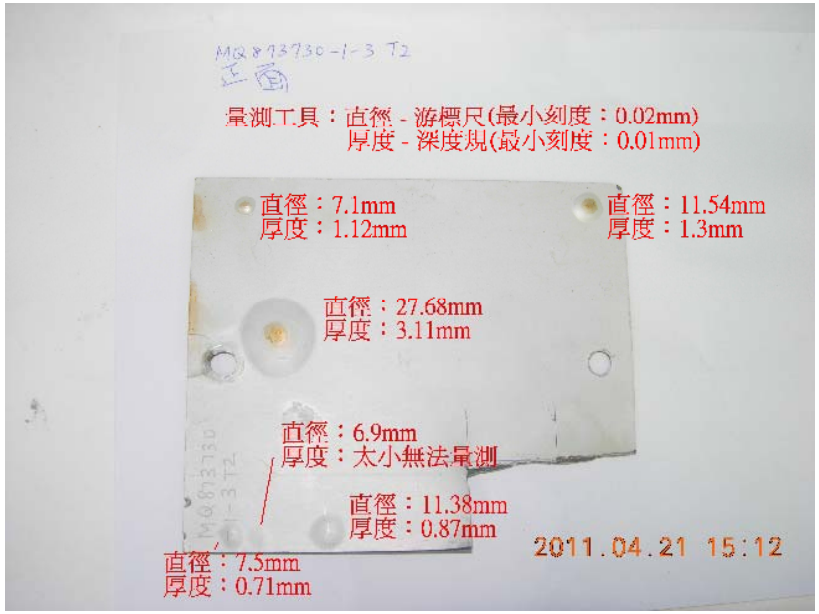
- In each SFP, there were 10 coupons mounted on the “coupon tree” and are positioned axially within the central 8 feet of the fuel zone, and the “coupon tree” is surrounded by freshly discharged fuel assemblies at each of the first five refueling outages following installation of the racks. From the fifth cycle on, the fuel assemblies surrounding the “coupon tree” remain in place for the remaining lifetime of the racks.
- Up to 2011, totally 9 boral test coupons have been examined. Two of the latest examined coupons showed blisters near the edge of the coupons.

Unit 1 2007.02

Unit 2 2011.02

Experience of Chinshan NPP (cont.)

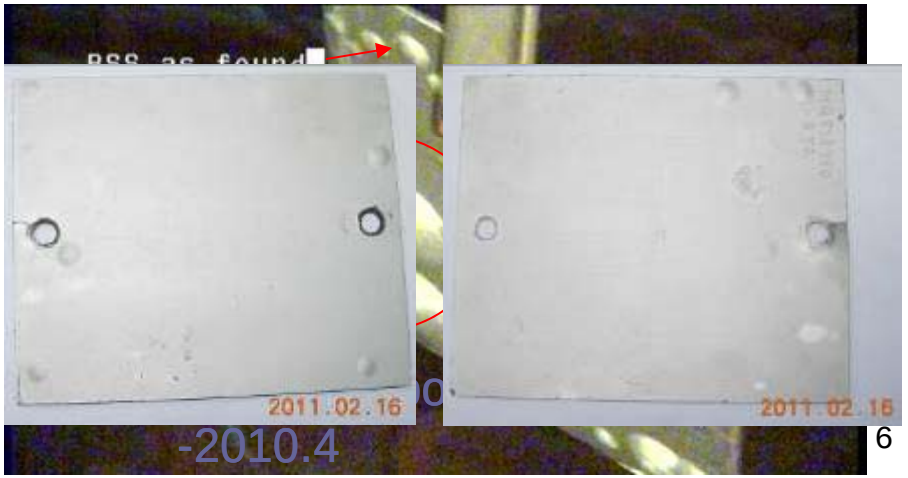
- Surveillance results of coupon taken out from Unit 2 in Feb. 2011.



Experience of Chinshan NPP (cont.)

- Considering test result of CS in 2007 and NRC IN 2009-26 , additional visual inspection was first conducted during the refueling outage of Chinshan unit 1 in April 2010.
- It was noticed that all of the six coupons remained in the pool were with blisters.
- The next test is scheduled in Chinshan Unit 1 in Oct. 2011.

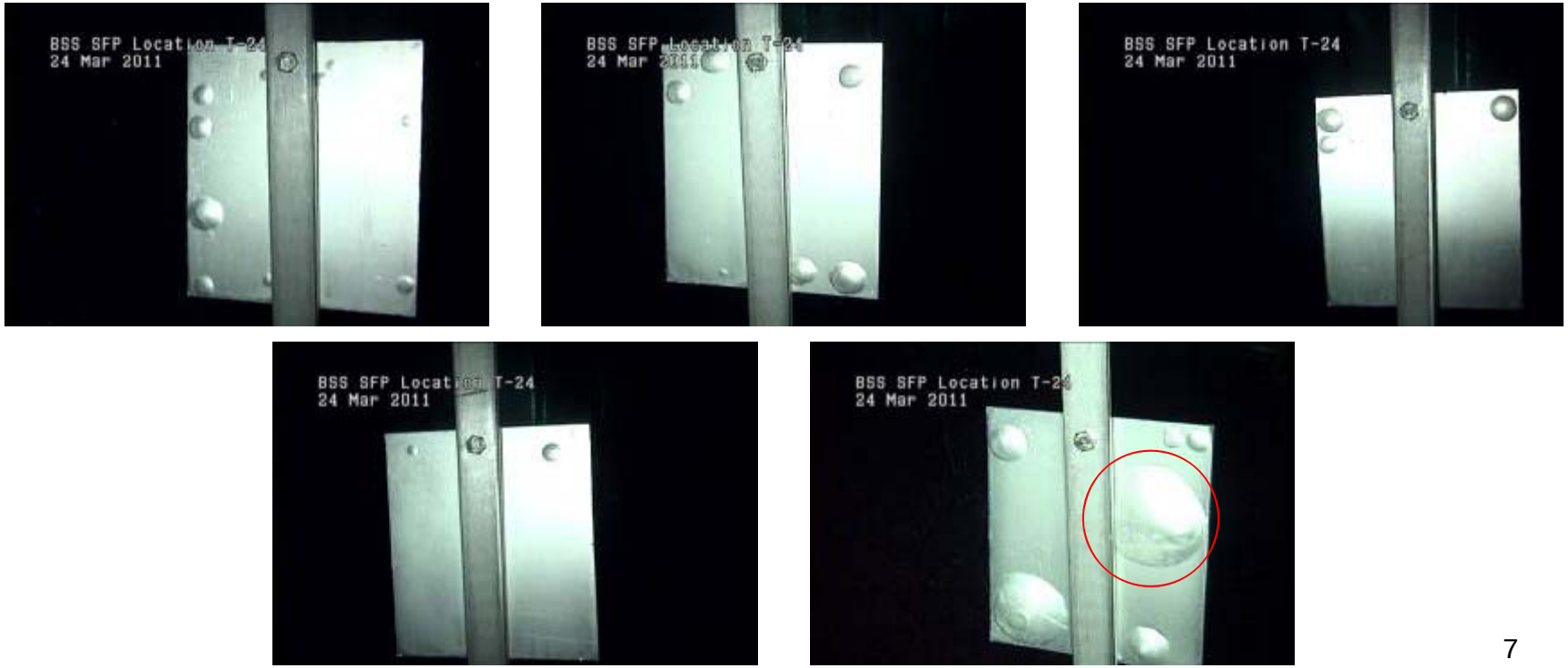
Unit 1 (coupon in pool) -2010.4



-2010.4

Experience of Chinshan NPP (cont.)

- In March 2011, a visual inspection was conducted during the refueling outage of Chinshan unit 2. All of the five coupons remained in the pool were with blisters.



Experience of Kuosheng NPP

- For Kuosheng NPP, the first re-racking which covers the major part of spent fuel pool (SFP) was done by Holtec in 1991. The second re-racking which covers the remaining part of SFP was done by Spanish company ENSA in 2003.
- Unlike the coupons of Chinshan, the Holtec Boral coupons at Kuosheng are jacketed in stainless steel, which do not show any blister or bulge. It is quite possible that no blister could form in the jacketed coupon.

Experience of Kuosheng NPP (cont.)

- Nevertheless, the non-jacketed coupons of the other manufacturer, ENSA, at Kuosheng had shown noticeable blisters through visual inspection during the refueling outage in March 2010, which is similar to Chinshan's operating experience.

Experience of Kuosheng NPP (cont.)

- There are 4 boral coupon trees in KS unit 1(2 Holtec/2 ENSA;K1-4) and 2 coupon trees in KS unit 2(ENSA;K5-6). Each tree has 8 coupons mounted on it.
- K-1, K-3 and K-5 “coupon tree” are for Long Term Surveillance, which are surrounded by freshly discharged fuel assemblies after the installation and remain in place for the remaining lifetime of the racks. Every 5 years a coupon test.
- K-2, K-4 and K-6 “coupon tree” are for Accelerated Surveillance surrounded by freshly discharged fuel assemblies at each refueling outages. Every refueling outage a coupon test. If it is within the Acceptance criteria, it can extend to two refueling outages or more.

Experience of Kuosheng NPP (cont.)

- Surveillance results of coupon trees K-1/ K-3/ K-5
  - K-1(2007.06)：3 coupons have been examined, no blister
  - K-3(2010.02)：1 coupon has been examined, no blister
  - K-5(2010.01)： 1 coupon has been examined, one blister with diameter around 1.5cm, thickness of the blister about 0.1cm
- Recent results of K-2/K-4/K-6 accelerated surveillance:
  - K-2(2010.02)： no blister
  - K-4(2011.02)： one blister (diameter ~1.3cm/ thickness ~ 0.1cm)
  - K-6(2011.01)： two blisters (diameter ~1.3cm/ thickness ~ 0.1cm; diameter ~ 1cm / thickness ~ 0.048cm)

Experience of Kuosheng NPP (cont.)

- Up to 2011/4/28, totally 17 boral test coupons have been examined. Recently examined coupons showed blisters near the edge of the coupons.

Acceptance Criteria for Boral Coupon Surveillance

- The test is performed at the onsite radiochemistry laboratory.
- Acceptance criteria for degradation/deformation of Boral surveillance are suggested by manufacturer.
- For CS:
  - The boron-10 contents shall be not less than the minimum allowed B-10 loading (0.0167 g/cm^2).
  - An increase in the thickness at any chosen point should not exceed 8% of the initial thickness at that point.

Acceptance Criteria for Boral Coupon Surveillance (cont.)

- For KS/Holtec:
  - The boron-10 contents shall be not less than the minimum allowed B-10 loading (0.011g/cm^2).
  - Thickness change at any chosen point should not exceed ± 1% of the initial thickness at that point.
  - Weight change of the coupon should not exceed ±1% of its original weight.
- For KS/ENSA:
  - The boron-10 contents shall be not less than the minimum allowed B-10 loading (0.02g/cm^2).
  - Thickness change at any chosen point should not exceed ± 8% of the initial thickness at that point.

AEC's regulatory activities

- Requested TPC to report CS and KS experience in using Boral through RAI.
- Requested TPC to inform Holtec about the results of Boral surveillance and visual inspection. It is our understanding that Holtec has to inform NRC about the material defects according to Part 21 unless it had reported to NRC before.
- Requested TPC to clarify potential safety impact, degradation mechanisms and study the possibility of in-situ and coupon neutron attenuation testing.
- There are no any regulations to ask TPC to provide the part 21 evaluations of Boral defect. AEC will include the request in the laws or regulations in the future.

Corrective Actions Taken by TPC

- Perform a justification that the effect of the blister was minor to criticality since no boron loss was found till now.
- Perform a friction test by using DUMMY bundle to verify the clearance between racks and fuel bundles to secure a practical fuel insertion activity to the racks.
- Holtec proclaimed that the blister was caused by hydrogen which generated from aluminum reacted with water in Chinshan. TPC considers that it's a likely cause of the blister and will establish a research project to understand the degradation mechanisms. The project is expected to be completed at the end of 2016.
- Aging management of spent fuel pool neutron-absorbing materials is adopted in the Aging Management Programs (AMP) of the Chinshan License Renewal Application (LRA).

Conclusion and Discussion

- There have been several runs of e-mail communications between NRC and AEC.

Questions from NRC	Response from AEC	Key points of communication
2010/09/13	2010/09/21	spent fuel pool conditions corrective; actions that are being taken; actual test results
2010/12/11	2010/12/27	Boral material in the Chinshan spent fuel pool (SFP) and actions taken to characterize the blisters
2011/01/15	2011/01/22	Except the letters between Taipower and Holtec, AEC agrees that others can be made public in ADAMS.
2011/01/22	2011/02/22	neutron absorbing material in the Kuosheng spent fuel pool (SFP) and actions taken to characterize the blisters
2011/04/22	To be discussed during BTM	General Neutron Absorbing Material Degradation Issues

Conclusion and Discussion (cont.)

- 2011/04/19 Questions from NRC
  - What materials are currently and potentially to be used at Taiwanese SFPs?
  - How are these materials qualified and validated prior to use in the SFP?
  - What is the expected lifetime of these materials in the SFP?
  - What types of degradation have been identified and how has it been mitigated?

Conclusion and Discussion (cont.)

- 2011/04/19 Questions from NRC (cont.)
  - What are AEC's regulations governing these materials?
    - What types of surveillance programs are at Taiwanese SFPs? What is the frequency of inspection? How does AEC ensure that these programs are effectively administered?
    - What inspection activities does AEC undertake to ensure compliance with these regulations?
    - Has AEC ever had to take enforcement action for failure to comply with these regulations?
    - Can AEC share copies of any pertinent regulations, inspection procedures, or enforcement activities with the USNRC?

Conclusion and Discussion (cont.)

- 2011/04/14 Questions from AEC
  - What's the safety significance of the degraded neutron absorption?
  - What are the current or future actions NRC going to take?

Thank You for Your Attention

NRC is interested in learning more about an event at Chinshan NPP and the swelling of boral coupons in the spent fuel pools. We would appreciate any further information that you can send. Specifically, we'd like to to know more about:

1. spent fuel pool conditions: temperature, what type of racks, conditions, etc.

(1) Normal operating temperature of spent fuel pool (SFP) is about 40℃ and maximum recorded temperature was 45℃.
(2) Holtec supplied the high density spent fuel rack with fixed neutron absorber material (Boral) positioned between the fuel assembly storage cells in a 0.076 inch space. Boral, a patented product of AAR manufacturing Inc, is a uniformly dispersed mixture of boron carbide (B_4C) and aluminum powders, clad in 1100 alloy aluminum sheets, and hot-rolled to produce an integral three-layer panel. The major construction material for rack is SA240-Type 304L stainless steel sheet and plate stock.
(3) The rack with 3083 cells storage capacity started to accept spent fuels since 2000. Until now, 2770 and 2636 cells are loaded with spent fuels for Unit 1 and Unit 2 respectively. The Unit 1 SFP lost full core reserve capability since recent refueling outage. The ISFSI of Chinshan NPP is still pending approval of local government.

2. any corrective actions that are being taken

(1) Sample and analyze spent fuel pool boron concentration once every other week. No significant variation was found.
(2) Aging management of spent fuel pool neutron-absorbing materials is adopted in the Aging Management Programs (AMP) of the recent License Renewal Application (LRA).

3. the actual test results

Based on site Boral surveillance program P1019 provided by Holtec, 4 tests were done at 1st, 2nd, 3th , 5th refueling cycles after rack was installed in 2000. Two different kinds of measurements were done at each scheduled test:

(1) Wet chemistry to verify that the boron-10 content shall be not less than the minimum allowed B-10 loading.
(2) Thickness measurement (as a monitor of potential swelling) to verify an increase in the thickness at any chosen points should not exceed 8% of the initial thickness at those points.

Until now, all the planned 4 test results meet the acceptance criteria. No evidence shows a gradual neutron-absorbing material degradation tendency.

The next test is scheduled in February 2011.

Additional Questions on the Degradation of Boral at Chinshan

After reviewing the Holtec Bulletin, HIB-44, and the responses from AEC dated September 21, 2010, the staff has some additional questions.

Specifically, the staff would like to know more about the Boral material in the Chinshan spent fuel pool (SFP) and actions taken to characterize the blisters:

- Please describe how the Boral panels and coupons are situated in the SFP. Are the Boral panels and coupons jacketed (e.g., wrapped in stainless steel) in the SFP? Are the coupons kept in areas of high neutron flux?

A: The rack module manufacturing begins with fabrication of the "box". The stainless steel sheathing is attached to each side of the box with a Boral panel installed in the sheathing cavity. The square cross section box with Boral panels affixed to its external surface is referred to as the "composite box assembly". The composite boxes are welded edge-to-edge to form as assemblage of storage cell locations. Both Boral panels and coupons are not jacketed.
Yes, 10 coupons mounted on the "coupon tree" are positioned axially within the central 8 feet of the fuel zone, and the "coupon tree" is surrounded by freshly discharged fuel assemblies at each of the first five refueling outages following installation of the racks. From the fifth cycle on, the fuel assemblies surrounding the "coupon tree" remain in place for the remaining lifetime of the racks. (The Unit 1 started from Mar. 2007 and Unit 2 from Sept. 2006)

- Please provide details of onsite Boral surveillance program, P1019 (as referenced in responses from AEC dated September 21, 2010).

A: 1. Test before Dried
(1) The coupon is washed with clean water or acetone.
(2) Dimensional measurements (length, width and thickness).
(3) Visual examination and photographic documentation of appearance.
2. Dried Stages:
(1) 4 hours at 80℃
(2) 4 hours at 150℃
(3) 4 hours at 260℃
(4) Repeat the above stages until a constant weight are obtained. Record the final weight.
3. Specific Gravity
4. Wet Chemical Analysis: cut a small piece (approximately 3cm × 3cm) for wet chemical analysis to get the boron density (g/cm^2).

- Please provide more information about the blisters including:

  - The Holtec report evaluating the blisters seen in the 2010 inspection.

A: Only HIB-44 "Swelling of Boral coupons from prolonged storage in fuel pools" was issued.

  - Were blisters seen in previous four surveillance campaigns? If so, what were the quantity and dimensions of the blisters?

A: Only the recent surveillance at Unit 1 in February 2007 showed 2 suspected blisters on each side of the coupon (see figures below). Dimensional measurement of blisters was not done at that time because they were suspected blisters and appeared the first time.

- The size and dimensions of all the blisters (Length, width, height/thickness).

A: No measurement was done. The width and length can be estimated proportionally by the pictures in HIB-44 with coupon size of 5" by 6" (width by length).

- Are the rates of blistering being trended?

A: No, data are not enough. However, in order to have more understanding on the degradation mechanisms of Boral, TPC is going to launch a research project to study the degradation mechanisms and to predict the rate of blistering.

- Please provide more information about the tests performed on the Boral coupons:
  - Was the testing of the Boral coupons performed onsite or in a lab?

A: In an onsite radiochemistry laboratory at Chinshan NPP.

  - Describe the tests performed.

A: Tests were performed per P1019 procedure.

  - What is the acceptance criteria for degradation/deformation of Boral?

A: (1) The boron-10 contents shall be not less than the minimum allowed B-10 loading (0.0167 g/cm^2).
(2) An increase in the thickness at any chosen point should not exceed 8% of the initial thickness at that point.

  - Describe if panel/coupon thinning is monitored.

A: Following the P1019 procedure, the thickness of 5 locations on the coupon is measured and compared to the initial thickness. An increase in the thickness less than 8% of the initial thickness is acceptable.

  - Any future plans for neutron attenuation testing? In-situ testing?

A: Yes, TPC will establish a research project to understand degradation mechanisms, perform technical development and study the possibility of In-situ and coupon neutron attenuation testing.

  - After testing, are the coupons re-inserted into the pool?

A: No, they were discarded in the past. In the future, the remaining parts of coupon will be re-inserted into the pool for comparison purpose (only for reference).

  - What types of testing are planned for the next scheduled test (2011)?

A: (1) Visual examination and photographic documentation of appearance
(2) Dimensional measurements (length, width and thickness)
(3) Wet chemistry
(4) Weight and specific gravity
The most important measurements are thickness (to monitor for swelling of the Boral coupons) and wet chemistry (a measurement of Boron-10 content g/cm^2)

In addition, the staff has some questions about how this Operating Experience was reported:

- Please provide the TPC part 21 evaluation of this material defect.

A: TPC did not provide the Part 21 evaluation of Boral defect. Initially, the problem was identified through AEC's RAI to Chinshan in accordance with US experience as reported in IN 2009-26. TPC was requested by AEC to inform Holtec about the results of Boral surveillance and visual inspection. It is our understanding that Holtec has to inform NRC about the material defects according to Part 21 unless it had reported to NRC before. A recent battery event at Kuosheng NPP, the vendor did inform NRC even it occurred in a foreign country (Part 21 Report no. 2010-20-00). AEC could not understand that with all the information provided by TPC, Holtec still chose not to send Part 21 or potential Part 21 report to NRC. (Correspondences between TPC and Holtec are attached)

- Please indicate if there are any additional plant SFPs affected by this operating experience in the TPC fleet.

A: Yes, Kuosheng nuclear power plant has similar experience. See the answer to the last question.

- Was this material degradation event disseminated in the international community? If so, please provide the report/letter.

A: Yes. AEC presented the findings in the Annual AEC/NRC Bilateral Technical Meeting held in Taipei on May 3-6, 2010 and Annual AEC/JNES Technical Exchange Meeting held in Taipei on November 30 - December 1. (The presentation materials are attached)
Note: Mr. Bill Ruland of NRR and Ms. Danielle Emche of OIP participated in the 2010 Annual AEC/NRC Meeting in Taipei.

- Is Holtec the manufacturer or the distributor of the Boral material used at Chinshan? Were other plants in the TPC fleet that use Boral notified by Holtec?

A: Holtec is the manufacturer of the racks and AAR Manufacturing, Inc. produced the Boral material used at Chinshan.
Part of the spent fuel pool racks of Kuosheng NPP were also supplied by Holtec. However, unlike the coupons of Chinshan, the Holtec Boral coupons at Kuosheng are jacketed in stainless steel, which do not show any blister or bulge. It is quite possible that no blister could form in the jacketed coupon. Nevertheless, the non-jacketed coupons of the other manufacturer, ENSA, at Kuosheng have shown noticeable blisters through visual inspection during recent refueling outage in March of this year, which is similar to Chinshan's operating experience.
Note: For Kuosheng NPP, the first re-racking which covers the major part of spent fuel pool (SFP) was done by Holtec in 1992. The second re-racking which covers the remaining part of SFP was done by Spanish company ENSA in 2005.

Response to Additional Questions on the Degradation of Boral at Kuosheng

After reviewing the Holtec Bulletin, HIB-44, and the responses from AEC dated September 21, 2010 and January 7, 2011, the staff has some additional questions.

Specifically, the staff would like to know more about the neutron absorbing material in the Kuosheng spent fuel pool (SFP) and actions taken to characterize the blisters:

- Where and by whom was the Boral in the ENSA racks manufactured?
  It was manufactured by AAR Corporation of Michigan.
  - Was this type of Boral similar to the one in the Chinshan spent fuel pool Holtec (e.g., porosity, materials of construction, B-10 content, etc)?
    For ENSA's rack, boron carbide is a fine granulated powder that conforms to ASTM C-750-80 Type III, the particles range in size between 60 and 200 mesh, minimum areal density of 0.02 $B^{10}g/cm^2$. In Chinshan Holtec rack, boron carbide contained in Boral is also a fine granulated powder that conforms to ASTM C-750-80 nuclear grade Type III with minimum areal density of 0.016B^{10} g /cm^2.

- It mentioned that in March 2010 blisters were also noticed on the ENSA rack coupons.
  - Was a part 21 evaluation done on this material defect?
    No, the situation is similar to the answer provided on January 7, 2011 regarding the part 21 report. TPC was requested by AEC to inform ENSA to do the part 21 on this material defect.
  - Please describe how the Boral panels and coupons are situated in the Kuosheng SFP.
    - Are the Boral panels and coupons jacketed (e.g., wrapped in stainless steel) in the SFP?
      ENSA's Boral panels are jacked but Boral coupons are not jacketed.
      - Are the coupons kept in areas of high neutron flux?
        Yes, they are moved to the most recent discharged fuels after each refueling outage except that the elevation of each coupon on the coupon tree is fixed.
      - Are the racks and coupon jackets vented?
        It is hard to be sure without more detailed drawing of the Boral panel jackets. However, Kuosheng's staff claimed that some small gas bubbles did come out of racks while ENSA's racks being installed into the spent fuel pool.
  - Please provide more information about the blisters including:
    - Was a report filed on these blisters? If so, please describe.
      Kuosheng performed visual inspection and surveillance on the coupons following the existed procedure, which is similar to Chinshan's program.
    - Were blisters seen in previous surveillance campaigns before 2010? If so, what were the quantity and dimensions of the blisters?
      Yes, there was one blister on each ENSA coupon surveyed in 2008. The diameters of the blisters were about 1~2 cm.
    - The size and dimensions of all the blisters (Length, width, height/thickness).
      The diameters of the blisters were about 1~2 cm. The other parameters such as height/thickness of the blisters were not measured. According to Kuosheng's staff, the height/total thickness was roughly 0.1cm/0.28cm, but it was not formally recorded.
    - Are the rates of blistering being trended?
      No, data are not enough and Boral coupon is disposed after each surveillance according to the current procedure.
    - Was the root cause of these blisters determined?
      Holtec proclaimed that the blister was caused by hydrogen which generated from aluminum reacted with water in Chinshan. TPC considers that it's a likely cause of the blister and will establish a research project to understand the degradation mechanisms.
    - What corrective actions, if any, were taken?
      The corrective actions taken by Kuosheng include:
      1. Perform a justification that the influence of the blister was minor to criticality since no boron loss was found till now.
      2. Perform a friction test by using DUMMY bundle to verify the clearance between racks and fuel bundles to secure a practical fuel insertion activity to ENSA racks.

- Please discuss whether there is a Holtec report evaluating the blisters seen in the 2010 inspection, if so please provide this report.
  Only HIB-44 "Swelling of Boral coupons from prolonged storage in fuel pools" was issued.

- Will Kuosheng also be part of the research study at TPC as mentioned in the January 7, 2011 response?
  Yes.
  - When will this study expected to be completed?
    The work scope of this study is still under discussion between TPC and The Institute of Nuclear Energy Research (INER). According to the preliminary project schedule, it is expected to be completed by the end of 2016.

- Will there be interaction with other licensees/plants, vendors, etc?
  According to the preliminary research plan, interaction with Boral vendors and/or EPRI is necessary.